Extending MODIS Deep Blue aerosol retrieval coverage to cases of absorbing aerosols above clouds: first results

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Absorbing smoke or mineral dust aerosols above clouds (AAC) are a frequent occurrence in certain regions and seasons. Operational aerosol retrievals from sensors like MODIS omit AAC because they are designed to work only over cloud-free scenes. However, AAC can in principle be quantified by these sensors in some situations (e.g. Jethva *et al.*, 2013; Meyer *et al.*, 2013).
We present a summary of some analyses of the potential of MODIS-like instruments for this purpose, along with two case studies using airborne observations from the Ames Airborne Tracking Sunphotometer (AATS; http://geo.arc.nasa.gov/sgg/AATS-website/) as a validation data source for a preliminary AAC algorithm applied to MODIS measurements.
AAC retrievals will eventually be added to the MODIS Deep Blue (Hsu *et al.*, 2013) processing chain.

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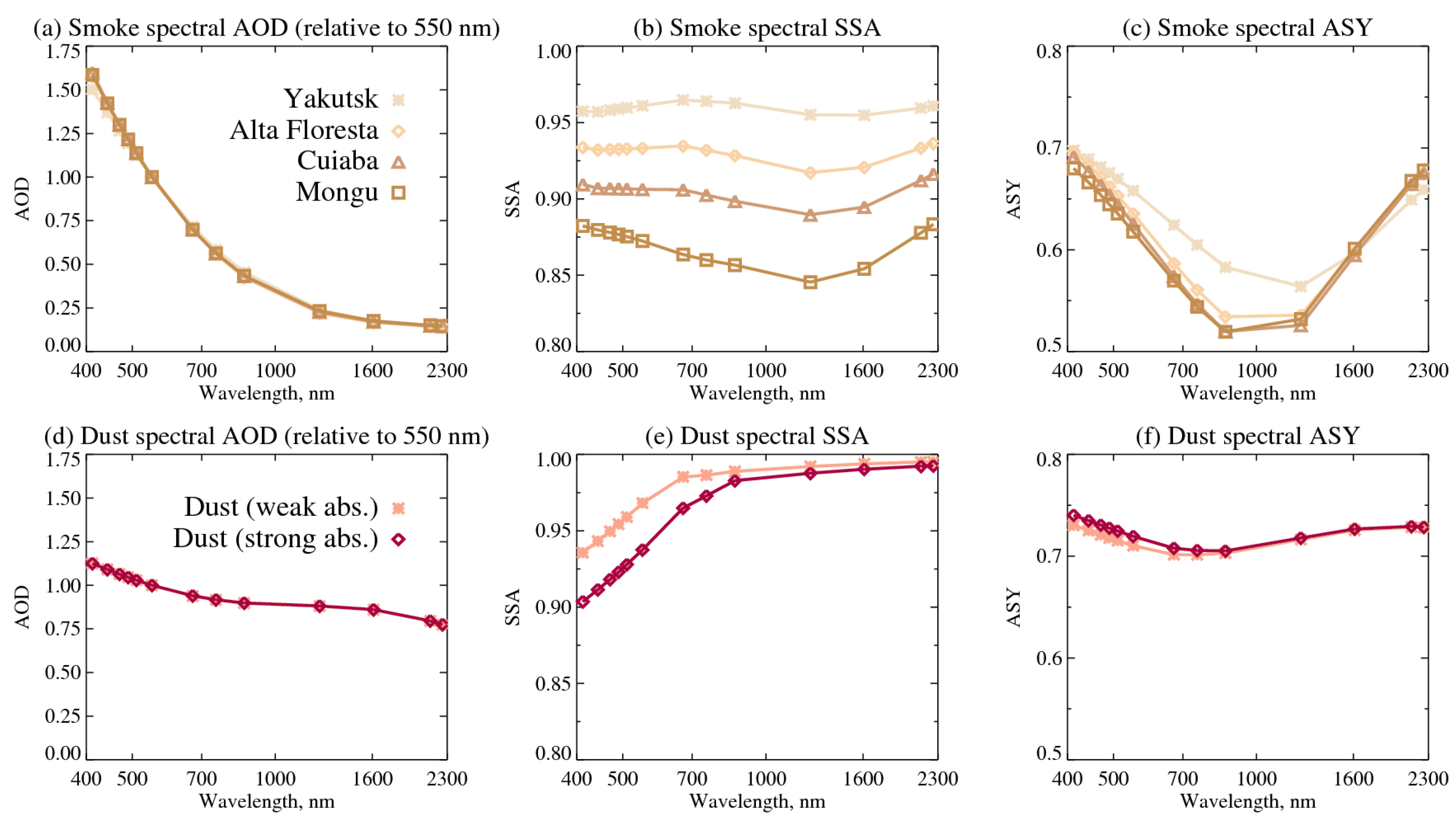
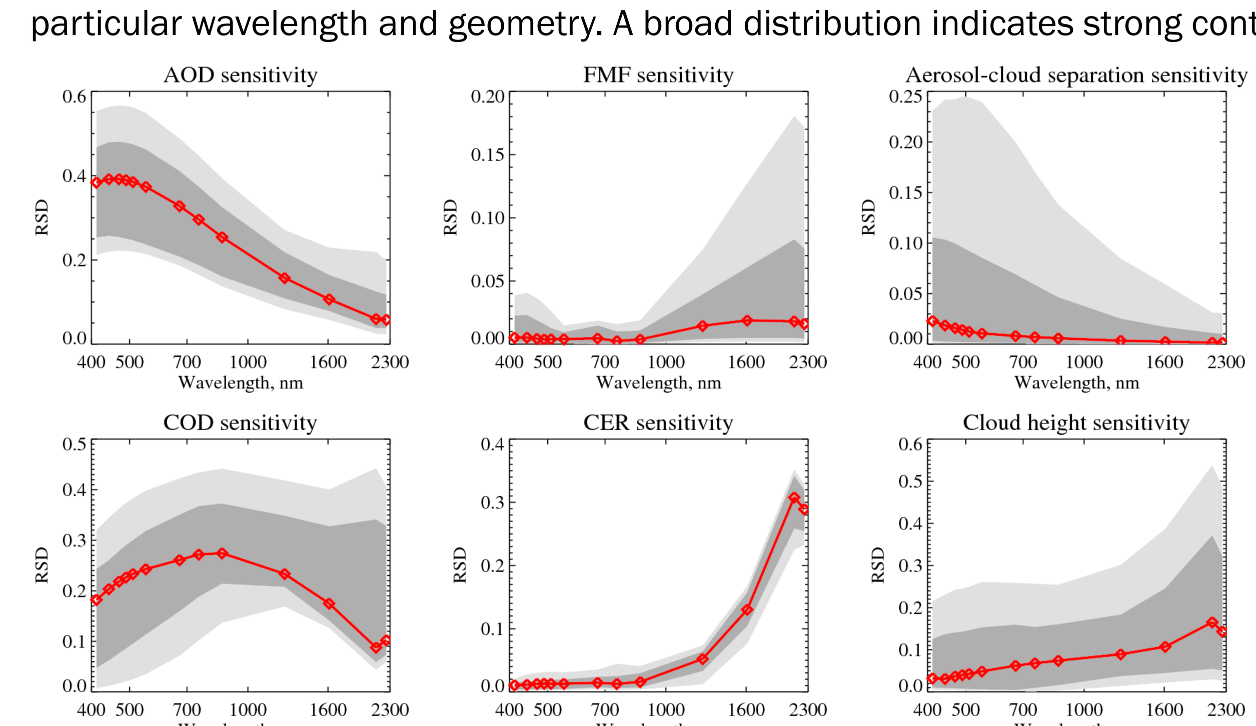
Representative optical models for smoke and dust aerosols



- We consider four smoke and two dust aerosol models for our simulations.
- For smoke, we use models from Sayer *et al.* (2014), spanning the common range of global smoke single scattering albedo (SSA) for burning near different Aerosol Robotic Network (AERONET) sites.
- For dust, we use the method of Lee *et al.* (2012), for models distinguished by different SSA.
- The above figures show the spectral dependence of aerosol optical depth (AOD), SSA, and asymmetry parameter (ASY) in these models for a reference 550 nm AOD of 0.5.
- Smoke models tend to have strong spectral dependence of AOD and ASY, but weak spectral dependence of SSA. For dust, the converse is true.

Sensitivity of MODIS-like sensor spectral bands to aerosol/cloud parameters

- We have performed extensive radiative transfer simulations of AAC situations. The plots below illustrate the relative sensitivity of various spectral bands to aerosol/cloud parameters for the case of smoke aerosols typical of central African burning (Mongu aerosol model), specifically: AOD, aerosol fine mode fraction (FMF), aerosol-cloud vertical separation, cloud optical depth (COD), cloud effective radius (CER), and cloud altitude.
- The relative standard deviation (RSD) of simulated reflectance across an ensemble of simulations holding all parameters bar one constant is shown. A larger RSD indicates greater sensitivity to that parameter for the particular wavelength and geometry. A broad distribution indicates strong contextual dependence of sensitivity.



- Shorter wavelengths are sensitive to aerosol-related parameters, due to the strong coupling between Rayleigh scattering and aerosol/cloud scattering and absorption.
- The midvisible range is sensitive to COD, which is intuitively expected.
- Longer wavelengths show limited sensitivity to aerosol properties (for this fine-mode-dominated case), but greater sensitivity to CER and cloud altitude.

AAC retrieval algorithm concept

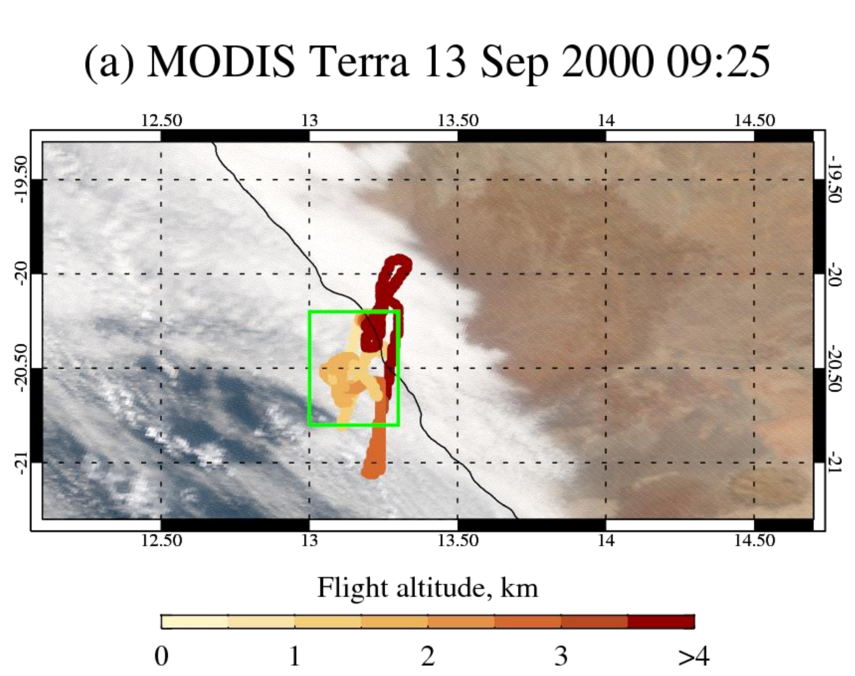
- We plan to **retrieve AOD, COD** and a choice between a small number of appropriate aerosol models, **using MODIS bands centered near 470, 550, 650, and 865 nm**, by a multispectral weighted least-square fit. For this demonstration, retrievals are performed at 1 km resolution.
- Omitting the 412/443 nm bands, which often saturate for MODIS for AAC cases, decreases ambiguities related to aerosol-cloud separation, SSA, and fine-mode aerosol fraction.
- Omitting the longer wavelengths decreases ambiguities related to cloud effective radius and altitude.
- Using synthetic data, **retrieval simulations suggest ~30% uncertainty on the retrieved AOD** (not shown here), dependent on situation, as a result of these simplifying assumptions.
- Using this spectral range, **the algorithm could also be applied to similar sensors** (e.g. SeaWiFS, VIIRS, MERIS, GOCI).
- Pixels with a poor fit to measurements, low COD, or poor sensitivity to AOD, will be discarded.
- Eventually, estimates of the direct radiative effect of these AAC cases will also be calculated.

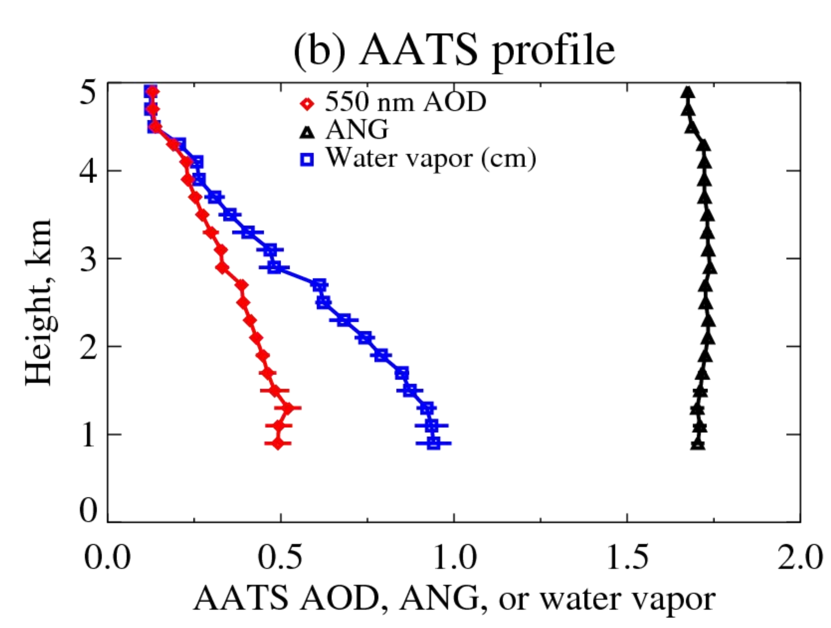
AATS provides one of the few opportunities for validating the algorithm

- AATS measures direct solar transmittance in, depending on configuration, 6 (AATS-6) or 14 (AATS-14) solar spectral bands.
- This allows the determination of columnar (aircraft to top-of-atmosphere) spectral AOD and water vapor with a similar quality to ground-based sun photometers (AOD uncertainty ~0.01-0.02).
- AATS has been mounted on airborne platforms and used in numerous field campaigns (e.g. Redemann *et al.* 2003, Schmid *et al.* 2003 for the experiments these case studies are drawn from).
- In a few cases, measurements have been taken in proximity to clouds near to the time of MODIS overpasses, providing rare opportunities for validating the AAC algorithm.
- Two such cases are illustrated below. Note AATS AOD has been interpolated spectrally to 550 nm.

SAFARI-2000, 13 September 2000

- AATS-14, aboard the University of Washington's Convair-580 off the coast of Namibia, spiraled over a stratocumulus deck of ~1 km altitude (based on simultaneous lidar observations) with an overlaying smoke aerosol layer, beginning around 30 minutes after a MODIS Terra overpass.

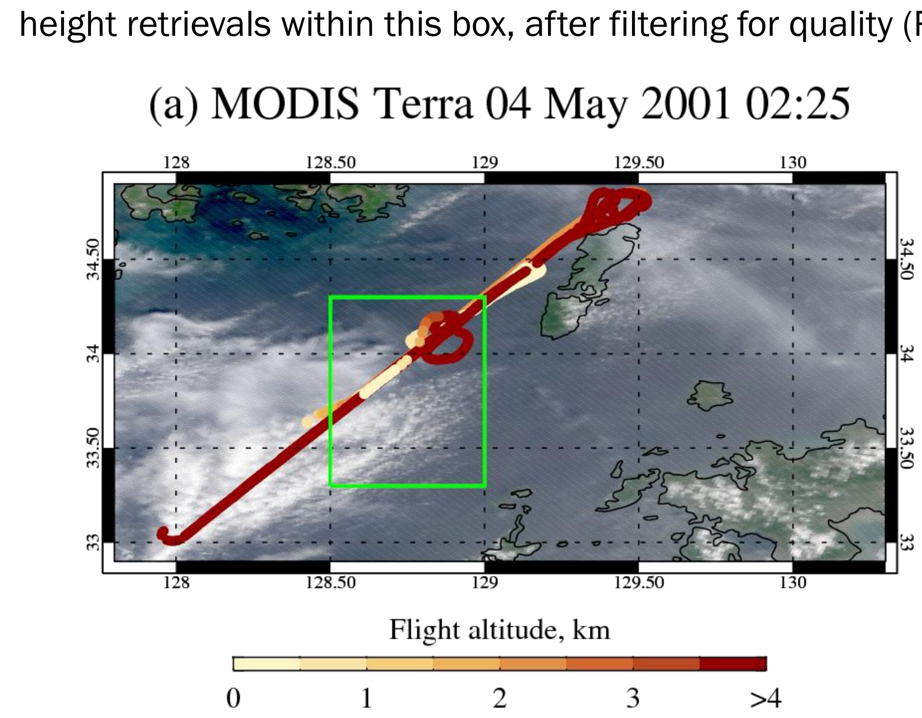


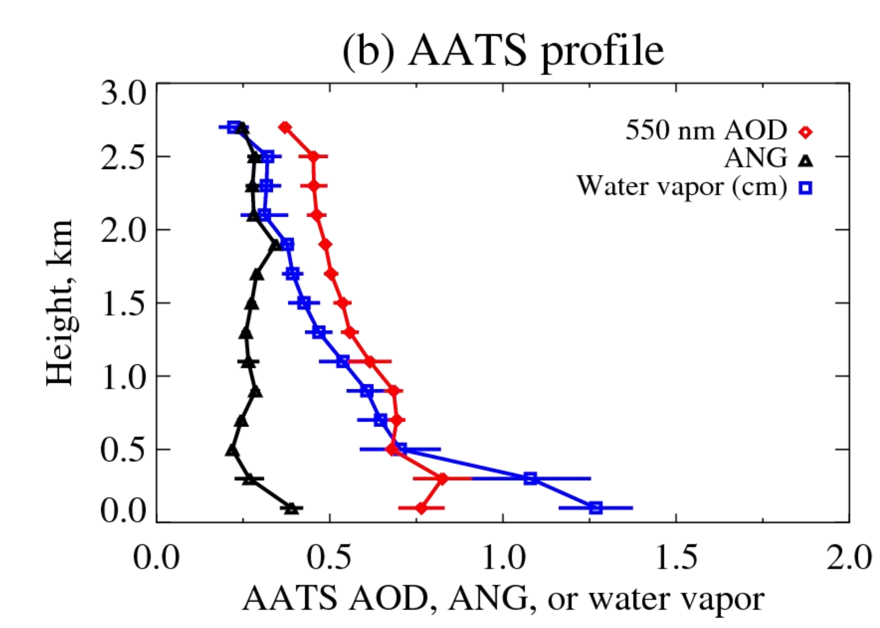


- The mean (+/- standard deviation) 550 nm AOD AATS measured from near cloud-top upwards, within the green box, was **0.49 +/- 0.04**. The Ångström exponent (ANG) around 1.7 is consistent with smoke.
- The corresponding AOD from our MODIS retrieval using the 'Mongu' aerosol model is **0.51 +/- 0.09**, showing good agreement, although higher spatial variability.
- Our COD retrievals are well-correlated with the operational MODIS cloud product, with a high offset of order 50% in the green box, which is as expected from the aerosol absorption given that no correction for these aerosols is presently made in the MODIS cloud product.

ACE-Asia, 4 May 2001

- AATS-6 flew aboard the US NSF/UCAR's C-130 flying between Korea and Japan. The aircraft spiraled near a stratocumulus deck with an overlying dust aerosol layer, between around 30 minutes before and 30 minutes after a MODIS Terra overpass. No cloud height ground truth data are available, but median MODIS liquid cloud top height retrievals within this box, after filtering for quality (R. Frey), is 1 km (central 68% of data 0.75–1.75 km).





- The mean (+/- standard deviation) 550 nm AOD AATS measured from 1 km upwards, within the green box, was **0.66 +/- 0.02**; the likely range is from 0.50 (if the cloud top is around 1.75 km) to 0.69 (if the cloud top is around 0.75 km). The Ångström exponent (ANG) ~0.3 is consistent with dust.
- The AOD from our MODIS retrieval using the 'weak dust' aerosol model is **0.62 +/- 0.06**, within this range.
- The COD for much of the water cloud field was too low for the AAC retrieval, so there a spatial mismatch between the AATS and AAC data, which may contribute to the AOD difference and variability.
- Our COD retrievals are well-correlated with the operational MODIS COD, and of similar magnitude, consistent with dust aerosols having weak absorption in the bands used for COD retrieval by the operational cloud algorithm.